Caltrans District 4 – Interim Mobile Terrestrial Laser Scanning Guidelines

Caltrans District 4 (San Francisco Bay Area) is seeing an increase in request for use of Mobile Terrestrial Laser Scanning (MTLS) on projects on the State Highway System (SHS). These requests are coming from Local Agencies, consultants, and internal Caltrans professionals. Because of the increase in the requests for the use of MTLS it has become necessary to establish interim guidelines for appropriate projects for its use as well as appropriate standards and specifications.

MTLS is an emerging technology that combines the use of a laser scanner(s), the Global Navigation Satellite Systems (GNSS), and an Inertial Measurement Unit (IMU) on a mobile platform to produce accurate and precise geospatial data. The data is initially adjusted by post-processed kinematic GNSS procedures from separate GNSS base stations placed throughout the project area. Then the GNSS solution is combined with the IMU information to produce geospatial data in the form of a point cloud. This point cloud is then adjusted by a local transformation to well defined points throughout the project area to produce the final geospatial values. The final values are then compared to independent check point measurements.

The use of the MTLS shall adhere to all of the requirements stated in the Caltrans Surveys Manual (CSM) and the Caltrans Safety Manual. Additionally, the accuracy standards of the MTLS products shall meet the requirements as stated in the Federal Geographic Data Committee's Geospatial Positioning Accuracy Standards. Part 3 of these standards is the National Standard for Spatial Data Accuracy (NSSDA).

Note: These Guidelines are based on anecdotal information from a few projects that have shown good results. As more information and analysis is performed revised guidelines will be written.

Note: A California Licensed Land Surveyor is required to be in responsible charge of a MTLS whenever the activities are part of those listed in Section 8726 of the Business and Professions Code.

http://www.leginfo.ca.gov/cgi-bin/waisgate?WAISdocID=47910823817+0+0+0&WAISaction=retrieve

Note: The approval authority of the use of MTLS on the SHS in District 4 is the District Field Surveys Office Chief.

Note: This document is the result of a collaborative effort between URS, Terrametrix3D, David Evans and Associates, Psomas, WHPacific, and Caltrans staff.

Mobile Terrestrial Laser Scanning Guidelines
Caltrans – District 4

Note: These guidelines will be superseded by statewide standards and specifications produced by Caltrans' Office of Land Surveys and approved by Caltrans' Surveys Management Board when produced.

I.) Background

Description of a Laser Scanner

A basic laser scanner instrument combines a pulsed laser emitting the beam, a scanner deflecting the beam towards the scanned area, and an optical receiver subsystem, which detects the laser pulse reflected from the target. One type of system calculates the final xyz values from the time of flight of the laser. Since the speed of light is known, the travel time of the laser pulse can be converted to a precise range measurement. Combining the laser range, scan angle, laser position from GNSS and orientation of the laser platform from IMU, highly accurate xyz-coordinates of the topographic points for each laser pulse can be calculated. The laser pulse repetition rate in combination with scanning mirror deflecting pattern determine lidar data collection rate. In the most advanced commercially available lidar systems, the data measurement rate is typically 50,000 - 200,000 measurements per second, which allows the user to collect highly accurate data of required ground point density within very short period of time.

A second type of system uses phase-based algorithms to calculate the range component described above instead of time of flight.

Description of GNSS

GNSS are satellite systems that are used for positioning, navigation, and timing applications. These systems at present include the U.S.'s Global Positioning System (GPS), Russia's GLONASS, the European Union's Galileo, and the Chinese Beidou system. These systems send out encoded signals that have a well-defined wavelength. A GNSS receiver receives these signals and trilaterates its position, as well as calculates its heading and its precise time.

Description of IMU and its use in the MTLS

An IMU is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, spacecraft, and MTLS systems.

Within the MTLS it aids the system to caluclate its xyz positions during periods of reduced or no GNSS reception.

II.) Project Selection

The following are factors to consider when determining if MTLS is appropriate for a particular SHS project:

- Safety
- Project time constraints
- GPS data collection environment
- Length/size of project
- MTLS system availability
- Traffic volumes and times

Typical transportation projects (data) for the use of MTLS include:

- Asset management
- Planning maps
- Forensic surveys
- Base maps
- Deformation surveys
- Design surveys
- As-builts
- Bridge clearance surveys
- Line of sight analysis
- Quarries and earth-moving volumes
- Urban mapping and modeling
- Coastal zone erosion analysis

Note: The value of the collected data is multiplied when it is "mined" for data for various uses and customers beyond its initial intended use.

III.) Equipment

Note: The MTLS equipment should be able to produce data for the intended use.

All of the equipment used to collect MTLS data, to control the data, and to collect the quality control check shots should be able to collect the data at the accuracy standards described below. This determination will be from the stated specifications for the equipment by the manufacture.

The data collection equipment including scanners, Global Navigation Satellite System (GNSS) units, and the Inertial Measurement Unit (IMU) shall also have the following requirements.

Mobile Terrestrial Laser Scanning Guidelines
Caltrans – District 4

A.) Scanners

Eye safety

The OSHA and Cal-OSHA guidelines shall be strictly followed for eye safety.

Below is information for OSHA STD 01-05-001

STD 01-05-001 - PUB 8-1.7 - Guidelines for Laser Safety and Hazard Assessment

● **Record Type:**	Instruction
● **Directive Number:**	STD 01-05-001
● **Old Directive Number:**	PUB 8-1.7
● **Title:**	Guidelines for Laser Safety and Hazard Assessment
● **Information Date:**	08/05/1991
● **Status:**	Archived

OSHA ARCHIVE

OSHA Instruction PUB 8-1.7 August 5, 1991 Directorate of Technical Support

Subject: Guidelines for Laser Safety and Hazard Assessment

A. PURPOSE. This instruction provides guidelines to Federal OSHA and Plan States compliance officers, 7(c)(1) consultants, and employee for the assessment of laser safety.

Additionally, the eye safety of the traveling public and other people should be considered at all times and the equipment operated in a way to ensure the eye safety of all.

Scan Density

The scan density is ultimately dependant on the traveling speed of the MTLS system. The speed of the vehicle while collecting data shall not exceed the systems ability to collect data at the required density to model specific features.

Useful Range of Scanner

Since a laser scanner is capable of scanning features over long distances, and since the accuracy of the scan data diminishes beyond a certain distance, care should be taken to ensure that the final dataset does not include any portion of point cloud data whose accuracy is compromised by the fact that it is outside the useful range of the scanner. The useful

range will be determined by factors such as the range and accuracy specifications of the individual scanner as well as the accuracy requirements of the individual project. Methods for accomplishing this might include the implementation of range and/or intensity filtering during data collection or culling any out-of-useful range data during post processing.

B.) GNSS

The GNSS equipment shall correspond with the requirements stated in Chapter 6, "GPS Surveys" of the CSM.

Additional GNSS equipment requirements:
- Dual frequency GNSS receiver able to receive data at 1 epoch per second or faster

C.) IMU

Below is an example of a manufacture's specifications.

The Table 1. shows the sensor specifications as reported by the producers:

Sensors	Specification	
Laser Scanner: FARO LS880	At 25m	3mm
Navigation System POSLV220	60 sec GPS outage	
XY position	15mm	
Z position	20mm	
Roll & Pitch	0.06°	
True heading	0.03°	

Table 1. Some sensor specifications

Mobile Terrestrial Laser Scanning Guidelines
Caltrans – District 4

IV.) Procedures

Following are the procedure requirements for a MTLS survey.

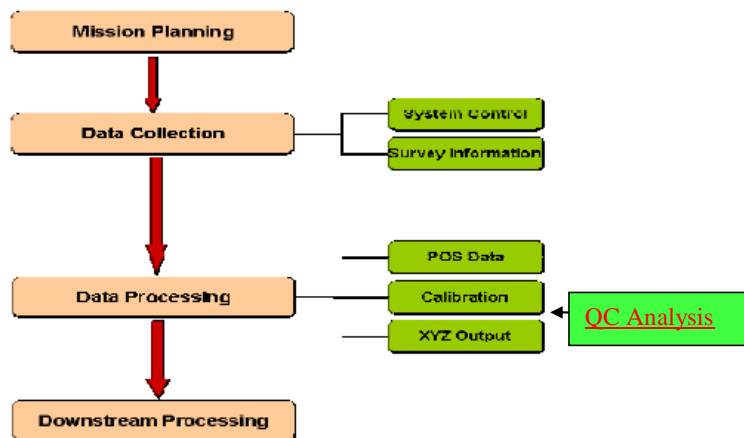**Note:** Refer to MLS Check List-1.0 at the end of this document.

Figure 1. Mobile lidar workflow

A.) *Establishment of GNSS Control Stations*

The GNSS Control Stations that will be used to control the post-processed kinematic adjustment of the MTLS data shall be placed at a maximum of 10-mile intervals to ensure that no processed baseline exceeds 5 miles in length. One of the base station's locations will be near the beginning of the project and another one near the end of the project.

The horizontal accuracy standard of the GPS Control Stations shall be second order or better as defined in the CSM and the vertical accuracy standard shall be third order or better.

Mobile Terrestrial Laser Scanning Guidelines
Caltrans – District 4

B.) *Mission Planning*

Before the MTLS project commences a mission planning session should be conducted to assure that there are enough satellites available during the data collection and that the PDOP meets the requirements.

During the data collection there shall be a minimum of 5 satellites in view for the GPS Control Stations and the GPS unit in the MTLS system. Additionally, the maximum PDOP during acquisition shall be 5.

Also, the project area shall be reconnoitered to determine the best time to collect the data to minimize excessive "noise" in the data collection from surrounding traffic or other factors.

C.) *Calibration of Equipment*

Before and after collecting the MTLS data all of the equipment in the MTLS system shall be calibrated to the manufacture's specifications.

D.) *Test Run*

In order to assure the accurate collection of the MTLS data a test run of data collection shall be conducted. The test run shall be of sufficient length and duration to assure that the system is functioning correctly and that the system is collecting data correctly.

Parameters:
- Length
- Known datum information on targets or physical features

E.) *Redundancy*

The collection of the MTLS data shall be conducted in such a way as to ensure redundancy of the data. This means that data should be collected so that there is an overlap, which means that either more that one pass in the same direction on the SHS project or overlapping passes in the opposite direction or both shall be collected.

Redundancy parameters:
- Overlap dimensions: minimum of 20% sidelap
- Time between runs: Sufficient time to ensure that the satellite constellation has at least 3 different satellites

F.)   *Monitoring of Data Collection*

Monitoring various component operations during the scan session is an important step in the QA/QC process. The system operator should be aware and note when the system encountered the most difficulty and be prepared to take appropriate action in adverse circumstances.

The MTLS equipment shall be monitored throughout the data collection to track the following as well as any other factor that needs monitoring:
- The loss of GPS reception and how long the IMU has drifted without correction.
- Vehicle Speed
- Proper functioning of the laser scanner

V.)   Local Transformation

A.)   *Description*

In order to increase the accuracy of the collected and adjusted geospatial data a local transformation of the point clouds shall be conducted. There may be many different types of local transformations that may be employed, however, the most common is a least squares adjustment of the horizontal and vertical residuals between established Local Transformation Points and the corresponding values from the point clouds to produce the transformation parameters of translation, rotation, and scale for the horizontal values and an inclined plane for the vertical values. These parameters are then applied to the point cloud to produce more accurate final geospatial data.

B.)   *Placement of Local Transformation Points*

The Local Transformation Points shall be evenly spaced throughout the project to ensure that the project is "bracketed". The maximum distance spacing between these points shall be a 500 feet on both sides of the SHS project, wherever possible.

C.) *Local Transformation Points Accuracy*

The Local Transformation Points shall be surveyed to third order or better for both the horizontal and vertical values as described in the CSM.

VI.) Quality Management Plan

The MTLS data provider shall provide to the District 4 Surveys Office Chief a Quality Management Plan (QMP) that includes descriptions of the proposed quality control and quality assurance plan.   The QMP shall include the requirements set forth in this document as well as other project specific QC/QA measures. See checklist.

The District 4 Surveys Office Chief shall conduct an Independent Quality Assurance (IQA) review of the QMP.

A.) *National Standard for Spatial Data Accuracy (NSSDA)*

The accuracy claimed of the finished MTLS geospatial data shall conform to the requirements stated in the NSSDA.

The NSSDA requirements can be found at the following link:
http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3

B.) *Number of Check Points Measurements*

According to the NSSDA, a minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the data sets.

Check point elevations shall be established with methods that produce a greater accuracy than the MTLS system provide. The preferred method is differential leveling to Caltrans Third Order Specifications.

VII.) Deliverables

One of the most inherent features of lidar data is that it is acquired, processed and delivered in digital format. This is one of the fundamental advantages of the lidar technology, which allows the user to generate lidar-derived end products, which are needed for a very wide range of applications. The simplest form of the processed lidar data is so called "point cloud", which could be saved in an ASCII format file containing xyzi geo-referenced data.

The point cloud data can be imported into various software packages including GIS, and others. Further data manipulation and/or fusing other type of data and analytical tools with the imported point cloud create a variety of value-added products.

Fig 2 gives and example of a point cloud dataset converted into a CAD model.
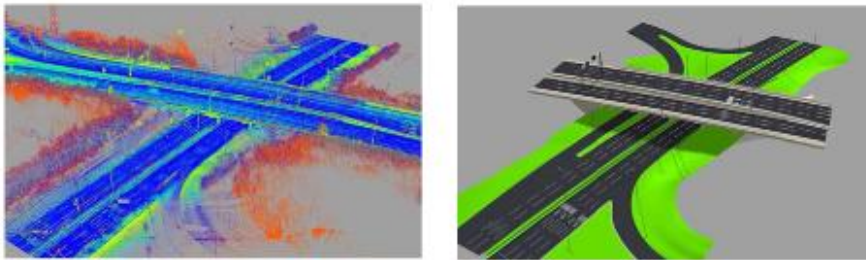

Figure 2 From point cloud (left) to CAD model (right)

The MTSL geospatial data deliverables vary from project to project.

A.) *QC report*

The QC report shall list the results of the MTLS including but not limited to the following documentation:

- Statistical system reports
- PDOP values during the survey
- Areas of the project that the data collected exceeded the minimum acceptable time of IMU drift due to GPS signal obstruction.
- Comparison of elevation data from different runs
- Comparison of points at the area of overlap if more than one base is used.

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- Statistical comparison of point cloud data and check points
- Statistical comparison of adjusted point cloud data and redundant check points

B.) *Point Cloud*

- When delivered the point cloud shall be filtered to one layer of points that represents the mean value of all the scans.
- The "noise" caused by moving vehicles and pedestrians shall be removed.

C.) *Additional Deliverables*

Additional products may be delivered as required by the customer.

Mobile Terrestrial Laser Scanning Guidelines
Caltrans – District 4
MTLS Check List 1.0

Materials Needed for Mobile Mapping Projects

A. Materials needed BEFORE the mission:

- ☐ 1) Who is the Project Manager?
- ☐ 2) Purpose of project mapping
- ☐ 3) Map units
- ☐ 4) Project coordinate system
- ☐ 5) Scanner calibration data
- ☐ 6) Proposed driving plan
- ☐ 7) GNSS visibility report
- ☐ 8) Suitable driving speed to obtain required point density
- ☐ 9) Proposed base station locations
- ☐ 10) Proposed Ground Control Points (GCPs)
- ☐ 11) Proposed schedule for delivery of Items B and C to the client
- ☐ 12) Driving Plan

B. Materials needed AFTER the mission and BEFORE vectoring:

- ☐ 1) GNSS accuracy report
  The GNSS Accuracy Report should contain the following:
  a. Forward/Reverse or Combined Separation plot
  b. Number of Satellites Bar plot
  c. PDOP, HDOP, VDOP plots
  d. L1 Satellite Lock/Elevation plot
  e. Estimated Position Accuracy plot

- ☐ 2) IMU accuracy report
  The IMU Accuracy Report should contain the following:
  a. IMU Position RMS plot
  b. GNSS/IMU Position Differences plot

- ☐ 3) Control report
  The Control Report should contain the following:
  a. Table showing the dZ between GCPs and known points
  b. Average, Minimum and Maximum dZ
  c. Average magnitude, RMS and standard deviation

C. Materials needed AFTER vectoring has been completed:

- ☐ 1) Classified point cloud (LAS and/or ASCII)
- ☐ 2) Georeferenced digital photographs/video